

ADAPTATION TO DISPLACED HEARING: A Non-Proprioceptive Change

by

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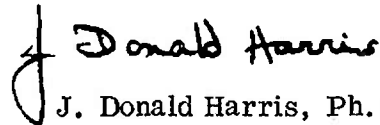
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SUMMARY PAGE

PROBLEM

To evaluate the "proprioceptive change" theory of visual adaptation in terms of its generality as a process underlying all types of sensorimotor adaptation, an experimental situation was employed where adaptation is produced by exposure to non-visual distortion (i.e., auditory rearrangement). If proprioceptive changes are basic to the production of adaptation to such sensory rearrangement, then inter-modal generalization which reflects proprioceptive change, should be evident following adaptation to auditory rearrangement.

FINDINGS

Results show that sensorimotor alterations following auditory rearrangement are confined to ear-hand responses and do not transfer intermodally to eye-hand coordination. These findings fail to support a "proprioceptive change" hypothesis of auditory adaptation and argue against its generality as a process underlying sensorimotor adaptation.

APPLICATION

These findings are useful in design of auditory passive detection systems employing auditory tracking. They are for use of systems designers and human factors applications where situations of perceptual rearrangement are anticipated. This information is of definite value to U.S. Navy medical practitioners in ear, nose, and throat and to audiologists.

ADMINISTRATIVE INFORMATION

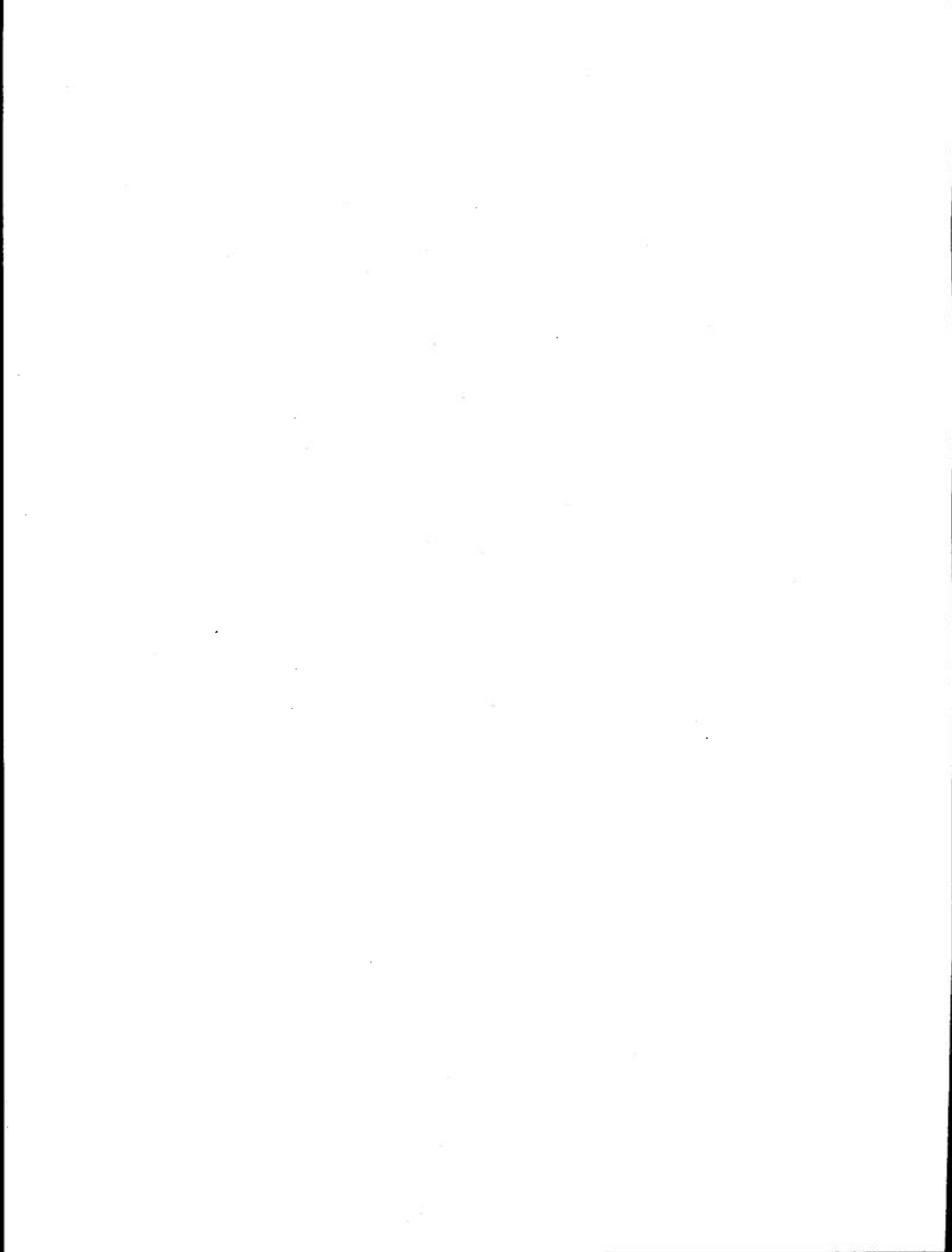
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ABSTRACT

Adaptation to rearranged ear-hand coordination, generated by exposure to an auditory tracking task entailing 30° of functional rotation of the interaural axis was explored using 12 Ss. The results show that sensorimotor alterations that follow such auditory rearrangement are confined to ear-hand responses and do not transfer intermodally to eye-hand coordinations. These findings fail to support the so called "proprioceptive change" hypothesis of auditory adaptation.



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INTRODUCTION

Prolonged viewing of optically displaced arm movements have been shown to produce changes in eye-hand coordination that are related to the direction and magnitude of the optical displacement (Efstathiou¹). Such response alterations following optical rearrangement are, however, not confined to the visual system. Pick, Hay, and Pabst¹⁰, Harris⁴, and others have reported similar concurrent changes in the auditory system (measured in terms of ear-hand coordination) as well as proprioceptive types of changes (measured in terms of the degree of accuracy in pointing straight ahead without visual guidance).

Generalization of adaptation to non-visual targets following visual rearrangement has led to several theories of sensorimotor adaptation (Rock¹²), the most successful being the "proprioceptive change" hypothesis proposed by Harris⁴. According to this theory, changes in pointing to visual (or non-visual) targets produced by viewing prism-displaced arm movements are the end product of changes in proprioception; or, more specifically, of changes in the felt position of the limb viewed through the displacing spectacles. A subject, viewing his arm displaced through prisms comes to feel his arm where it appears to be, thus producing a change in the felt position of the arm relative to his body. In reaching for a target subsequently viewed with the naked eye (arm made not visible by means of an opaque

screen) he will move his arm until it feels to be in the "correct" place though it will actually be off to one side (after-effect of adaptation). Since the change is in the felt position of the arm, pointing to an auditory target or just simply to straight ahead will manifest the adaptive shift (Harris⁵).

Although the "proprioceptive change" theory of adaptation is reasonable and economical, its generality as a process underlying sensorimotor adaptation is not established. The theory has emerged from short term studies of visual rearrangement and needs to be examined in experiments where adaptation is produced by exposure to non-visual distortion.

If changes in proprioception are basic to the production of adaptation to sensory rearrangement, then inter-modal generalization (transfer of adaptation to another sense modality) which reflects proprioceptive change, should be evident following adaptation to non-visual rearrangement. Auditory displacement provides an adequate condition in which to test this possibility. Adaptation to auditory rearrangement is usually produced by having a blindfolded S move a hand-held sound source while listening through pseudophones that functionally rotate the interaural axis. The direction and magnitude of the differences between pre- and post-exposure localizations of an auditory target are systematically related to the rotation of the interaural axis (Freedman et al.,³ Mikaelian⁹). If proprioceptive

change or an alteration in the "felt position" of the limb occur during exposure to auditory rearrangement, then shifts in pointing to auditory as well as to visual targets should be evident after adaptation.

The following experiment was designed accordingly.

METHOD

Subjects. The Ss were 12 undergraduate and graduate students with no apparent auditory or visual defects.

Apparatus. Pseudophones (a binaural microphone/earphone array worn on the head) were used to functionally rotate the interaural axes. The pseudophones employed a pair of highly directional condenser microphones (Altec 21 microphone compliment) fitted with plastic cast pinnae. These were mounted 7 1/2 in. apart on a lucite bar measuring 2x8x1/4 in. and pivoted at its center on the metal connecting band of a headphone set. When the headphone was worn by S the lucite bar supporting the microphones rested on his head and could be rotated in the horizontal plane. Pointers on the headphone indicated pseudophone rotation in degrees. The output from each microphone was amplified separately (Western Electro Acoustic Laboratory Type 100 D/E amplifier) and fed into its corresponding left or right headphone (Permoflux PDR-8). The desired angular displacement of the interaural axis could be produced by rotating the lucite bar which in turn displaced the auditory field laterally towards the leading ear.

The testing apparatus was a semi-circular masonite board (20x95 in. panel curved to a radius of 30 in.) that was mounted at eye level on a Dexion metal frame. It served to support the targets and the paper on which S, seated with his head on a chin rest at the geometric center of the curved board, marked their perceived location. The targets consisted of an earphone (auditory target) and a dim point light source (visual target) both mounted on a wooden block hung on the curved board. The position of the target block on the test apparatus could be varied. For the present experiment target position was varied randomly during training but was 8° left or right of straight ahead during testing. The relatively frontal target test positions were chosen to reduce substantial stretching of the arm that would have otherwise been necessary for S to locate a target whose orientation was displaced 30° by the pseudophones.

Procedure. Training, exposure, and testing (ear-hand coordination) procedures used in this experiment were similar to those reported earlier (Mikaelian⁹). During training S, listening through pseudophones in normal orientation (pseudophone axis parallel to interaural axis), practiced locating the sound target while blindfolded. The stimulus emitted by the target was generated by a Grass stimulator model S-4CR and consisted of wide band pulsed noise (30 msec. on and 60 msec. off) at 65 dB SPL (re 0.0002 dynes/cm²). It was switched on by E for as long as necessary for S to locate the target. Exposure was also conducted while blindfolded and entailed

moving a hand-held sound source in a semicircular path around the head while listening to the same sound stimulus heard during training, but now with the pseudophones' axis rotated 30°.

Testing consisted of (1) ear-hand coordination, for which the blindfolded S, listening through pseudophones with axis rotated by 30°, marked the position of the auditory target on the test apparatus (pre-exposure test markings always manifested a 30° angular displacement relative to those made during training with the pseudophones in normal orientation), and (2) eye-hand coordination, where S marked the position of the visual target. Each target was localized five times. Position of the target left or right of straight ahead was randomized, but remained constant for a given experimental session. Although S wore opaque goggles through the experimental session, during eye-hand tests the goggles were removed with the room darkened so that S could not see his marking hand.

An experimental session (except for training) consisted of: (1) pre-exposure tests of ear-hand and eye-hand coordinations, (2) a 20 minute exposure to auditory rearrangement, and (3) post-exposure tests of ear-hand followed by eye-hand coordinations. Since ear-hand tests were always made with pseudophones rotated by 30° (same as during exposure), changes in post-exposure ear-hand tests measured adaptation rather than the more commonly reported aftereffect of adaptation. Furthermore, it was felt that testing ear-hand coordination first following the 20 minute exposure was essentially equivalent to continued

rearrangement, a procedure that prevented any decay of adaptation (known to occur when eye-hand was tested first). Pilot experiments showed no differences in eye-hand coordinations when, following exposure, these were measured before and after ear-hand tests. Direction of pseudophone axis rotation (left or right ear leading) and the arm used for exposure were counterbalanced.

RESULTS

The results are shown in Table 1. The numbers indicate in degrees of angular displacement, the mean difference between the centroids of the pre- and post-exposure target localizations. Positive numbers indicate changes that compensate for the displacement initially induced by the pseudophones.

Negative numbers represent unadaptive changes. Positive changes in visual localization indicate eye-hand coordination changes that are in the same direction as the adaptive auditory changes.

The data show that adaptive shifts in ear-hand coordination occur following auditory rearrangement. The one condition where these shifts fail to reach statistical significance (t-tests) is the left-ear leading right-hand exposure condition, where the changes in ear-hand coordination are quite variable. No reliable changes in eye-hand coordination are observed following any of the rearrangement conditions.

Table I. Changes (in degrees of angular displacement) in Ear-hand and Eye-hand Coordination following 20 min. of exposure to 30° of Interaural Axis Rotation

Subjects	Left Ear Leading				Right Ear Leading			
	Left Hand		Right Hand		Left Hand		Right Hand	
	Audit.	Visual	Audit.	Visual	Audit.	Visual	Audit.	Visual
1	4.5	0.0	2.5	0.0	2.3	0.0	4.0	0.75
2	2.3	0.0	6.0	0.5	3.5	1.5	4.2	1.0
3	5.5	0.0	1.0	1.0	-1.0	0.0	2.5	1.0
4	14.5	0.5	-0.5	0.0	2.0	1.5	14.5	1.6
5	2.8	0.0	-1.8	0.0	-1.8	0.0	-3.5	-1.8
6	2.4	0.8	-4.2	0.0	3.0	0.5	1.25	0.0
7	9.5	0.5	8.0	0.0	9.3	0.5	15.7	2.5
8	2.5	0.0	0.75	1.0	2.75	-1.0	2.5	0.0
9	-4.2	0.5	-1.8	0.0	8.5	-2.0	3.8	1.1
10	3.9	-1.0	13.0	-0.5	2.0	0.0	-2.0	0.0
11	4.0	0.75	4.0	-2.5	1.5	0.0	2.0	0.25
12	1.0	-1.0	-2.0	-2.25	2.0	0.0	5.75	-1.5
MEAN ADAPTATION	4.06	0.09	2.08	-0.23	2.84	0.08	4.23	0.41
t(two tailed)	0.01	N.S.	N.S.	N.S.	0.01	N.S.	0.05	N.S.

DISCUSSION

The results show that 20 min. of exposure to auditory rearrangement produces significant auditory adaptation but fails to systematically modify eye-hand responses. Although occasional changes in visual localization are evident, these are not correlated with the magnitude of the concurrent auditory shifts. The fact that non-auditory target localizations remain unaltered following adaptation to auditory rearrangement indicates that this type of adaptation is confined to the auditory system, a finding that is contrary to the predictions of the "proprioceptive change" theory and argues against its generality as a process underlying sensorimotor adaptation.

Our failure to obtain intermodal generalization might have been due to the short exposure period utilized in the present experiment. Longer exposure would have increased adaptation so that intermodal transfer could, perhaps, have occurred. Evidence concerning long term exposure, however, suggests otherwise. Hay and Pick⁶ reported that while prolonged visual rearrangement produces substantial visual adaptation, the alterations of non-visual responses observed early in exposure gradually drop out, thus suggesting that intermodal effects are transient. Rekosh and Freedman¹¹ report similarly transient intermodal generalization following prolonged visual rearrangement. Clearly if intermodal effects drop out during long term exposure to visual rearrangement it is not likely that these would be amplified during long term exposure to auditory rearrangement.

Various theoretical formulations of processes underlying adaptation have been evaluated by Harris⁵ on the basis of their predictions concerning intermodal generalization. He has argued against the "sensorimotor recorrelation" theory of adaptation proposed by Held⁷ on the basis that it predicted adaptation to be confined to the sensory system that was rearranged. The specificity of adaptation shown by our results are in line with predictions of that theory. It should be pointed out, however, that although our findings do not support a "proprioceptive change" hypothesis of adaptation to auditory rearrangement, they do not of course, exclude the possibility that such changes occur in visual rearrangement, and point to the need for further experimentation to explore the issue.

One additional feature of our present data needs to be underscored. With left-ear leading, larger adaptive shifts are produced when the sound source is moved by the left than the right arm. Symmetrically, with right-ear leading, larger shifts are produced with right arm exposure. Although these differences do not reach statistical significance, they are similar to observations reported in prism studies, where the magnitude of adaptation appears to be a function of a combination of prism base orientation and the laterality of the limb viewed during rearrangement (Freedman and Wilson², Mikaelian⁸). Whether this is a procedural artifact is not clear and should be determined by additional studies.

SUMMARY

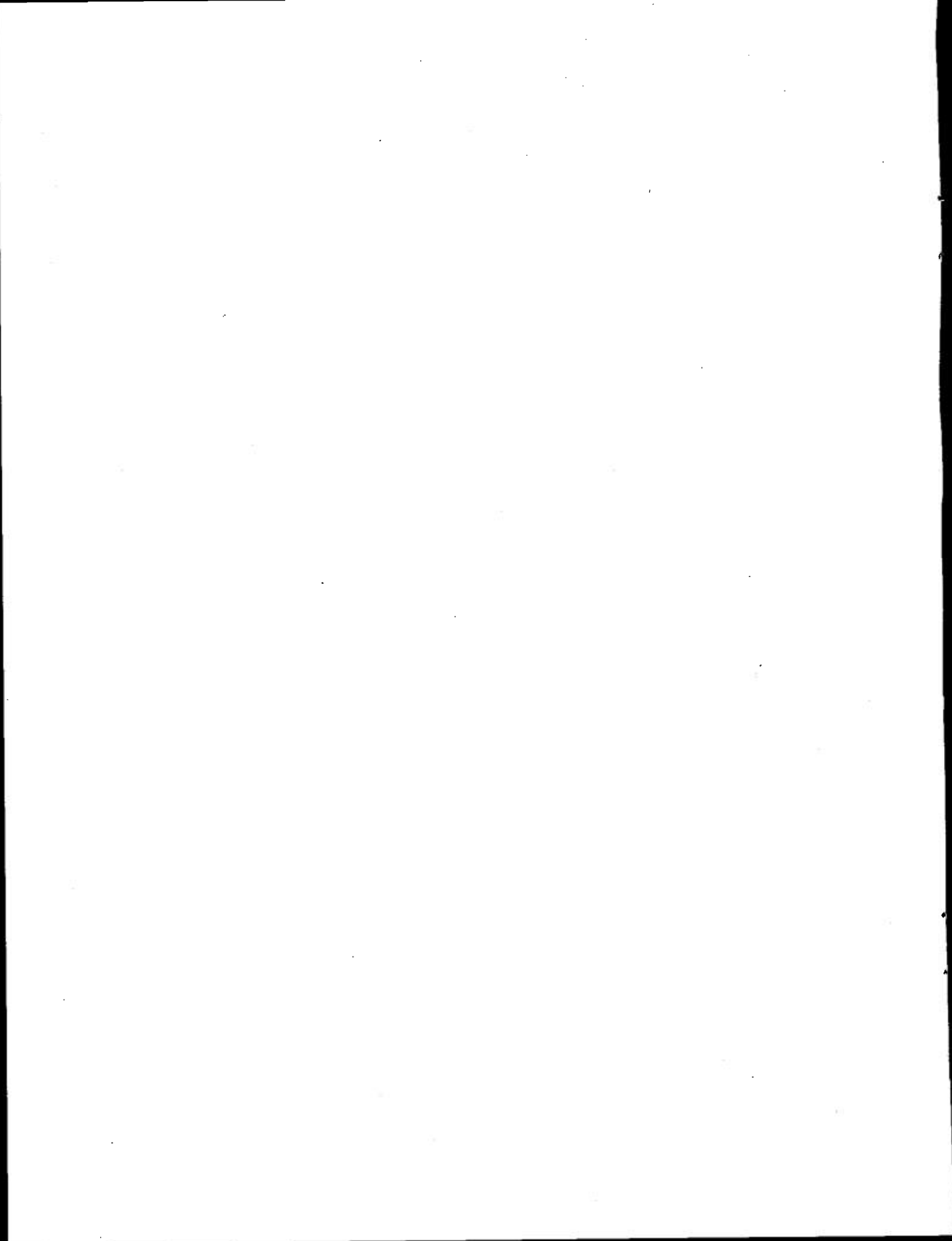
An electronic pseudophone (a binaural microphone/earphone array worn on the head) was used to functionally rotate the interaural axes of twelve blindfolded Ss, thereby causing a perceptual rearrangement of the environment. Subjects' ability to localize sound and light sources was tested prior to and after a twenty minute period of exposure to a handheld sound source rotated about the head. The results exhibited the expected adaptation to the auditory target, while there was no change in localization with respect to the visual target.

These results show that sensorimotor alterations that follow auditory rearrangement are confined to ear-hand responses and do not transfer intermodally to eye-hand coordination. These findings fail to support a "proprioceptive change" hypothesis of auditory adaptation.

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